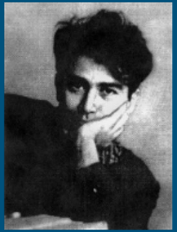
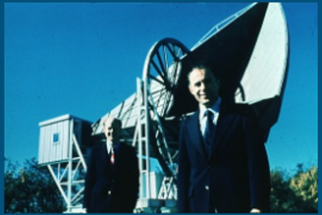
Radio Detection of High Energy Particles

Peter Gorham (U. Hawai'i)

With many thanks to David Saltzberg (UCLA)

The 60's





1961: First 10^{20} eV cosmic ray air shower observed

– John Linsley, Volcano Ranch, near Albuquerque, NM

1962: G. Askaryan predicts coherent radio Cherenkov from showers

– His applications? Ultra-high energy cosmic particles

1965: Penzias & Wilson discover 3K echo of the Big Bang

– (thermal noise from bird dung in their dish?)

1966: Cosmic ray spectral cutoff at $10^{19.5}$ eV predicted

– K. Greisen (US) & Zatsepin & Kuzmin (Russia), independently

Cosmic ray spectrum *must end* close to $\sim 10^{20}$ eV

END TO THE COSMIC-RAY SPECTRUM?

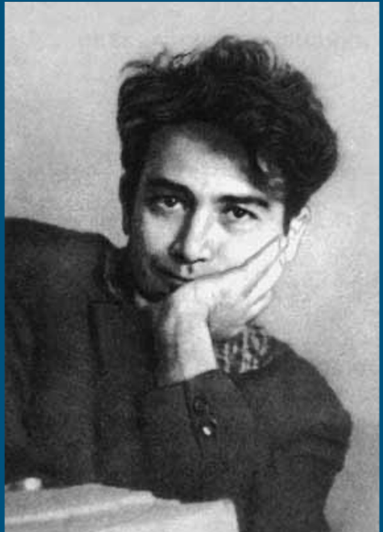
Kenneth Greisen

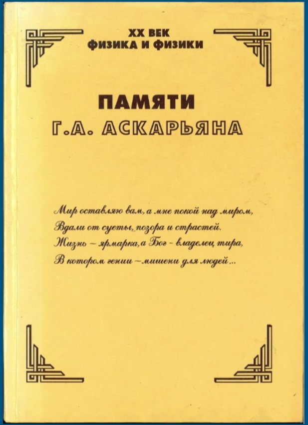
Cornell University, Ithaca, New York

(Received 1 April 1966)

Berezinsky & Zatsepin drew the important conclusion: there must be **cosmogenic UHE neutrinos**

Askaryan's application: Use Large Natural Media, Transparent to Radio





G. Askaryan biography: Boris Bolotovskii

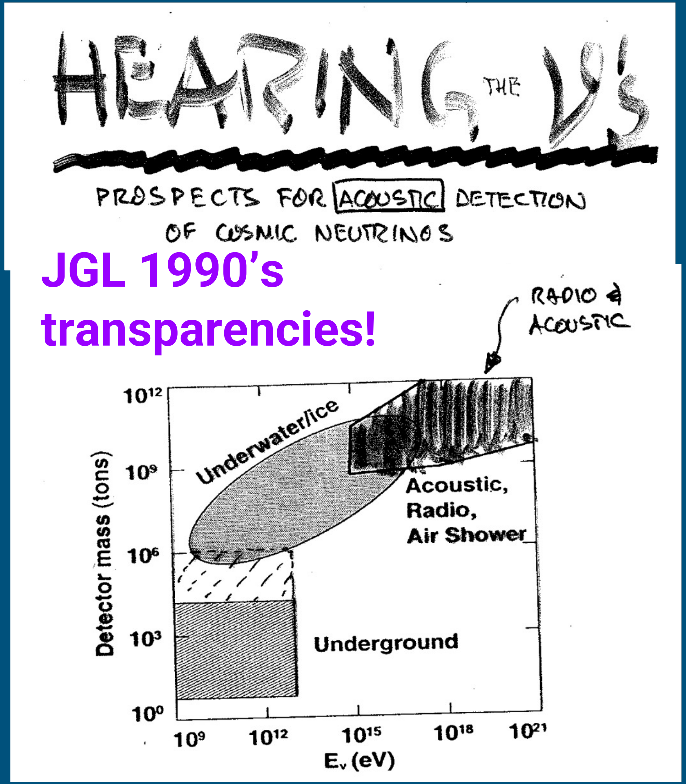
Gurgen Askaryan (1928-1997): prominent Soviet-Armenian physicist, discoverer of self-focusing of light, pioneer in light-matter interactions, and visionary in interaction of high energy particles with matter (and a Nobel contender…)

- Mapped it out in the 1960s:
- Lunar Regolith
  - combines two Greek words: *rhegos* (ῥῆγος), 'blanket', and *lithos* (λίθος), 'rock'.
- Antarctic Ice
  - Up to 4km deep
- Salt domes
  - Uplifted & purified ancient Sea Beds

G. A. Askaryan, 1962, JETP 14, 441; 1965, JETP 21, 658, ...

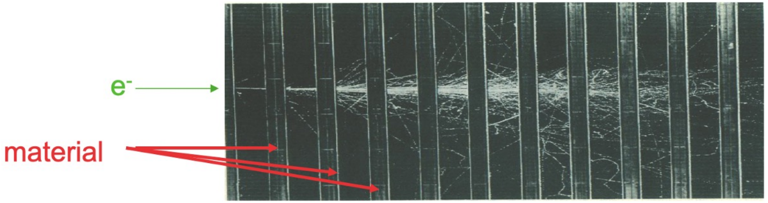
Askaryan's missed Nobel

- While a PhD student in the late 1940's, Askaryan came up with the idea to measure HE particles via supercritical fluids – the bubble chamber!
- He did not get much support from his institute, got discouraged and never published the idea
- A few years later Donald Glaser published the bubble chamber paper, resulting in a Nobel prize in 1960
- After that Askaryan published everything! Including: **acoustic detection of HEP**
- → **JGL took this and ran with it in a wonderful series of accelerator experiments that inspired a similar set of radio tests**



The Askaryan Effect

UHE event will induce an e/γ shower:



In electron-gamma shower in matter, there will be ~20% more electrons than positrons.

Compton scattering: $\gamma + e^-_{\text{(at rest)}} \rightarrow \gamma + e^-$

Positron annihilation: $e^+ + e^-_{\text{(at rest)}} \rightarrow \gamma + \gamma$

As is well known to this audience:

$P_{\text{Cherenkov}} \propto \nu\, \Delta\nu$ (includes radio!)

- High Energy showers create radio.
- Assuming
  - There is a charge excess of 10-30%
  - Coherence factor among 10^{10} charges
  - No “plasma shielding”
  - No **unknown unknowns** (haha).
- Had to convince the field
- Modern simulations
  - first by Francis Halzen, Enrique Zas, Todor Stanev further established effect, George Frichter & John Ralston at KU
  - FH: "I stake my career on it!"
  - Much subsequent theory work by Jaime Alvarez-Muñiz, Enrique Zas, Dave Seckel, many others

Pioneering work by Dave Besson with antennas on Amanda strings
and pioneering ideas by Dagkesamanskii, Gusev, & Zheleznykh, incl. at Russian Antarctic base, Vostok

R. Dagkesamanski & I Zheleznykh 1980’s

Inspired work on how to observe EHE CRs & neutrinos using ground based radio telescopes

Two very good radio astronomers, Tim Hankins and Ron Ekers, took them seriously and did the (single-dish) experiment!

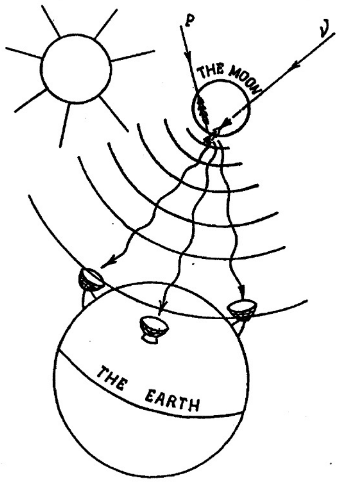
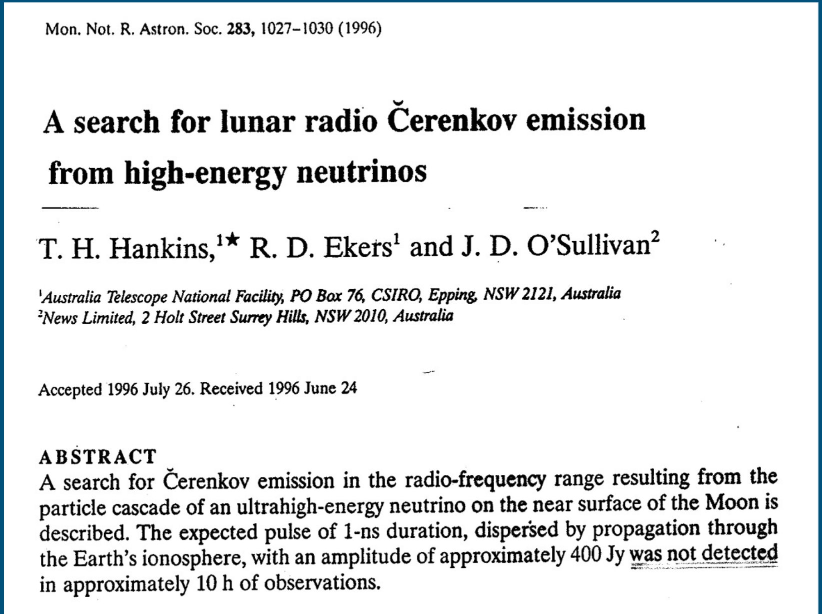


Fig.1 - A scheme of RAMHAND - Radio Moon Hadron and Neutrino Detection



Mon. Not. R. Astron. Soc. 283, 1027–1030 (1996)

A search for lunar radio Čerenkov emission from high-energy neutrinos

T. H. Hankins,[1★] R. D. Ekers[1] and J. D. O’Sullivan[2]

[1]*Australia Telescope National Facility, PO Box 76, CSIRO, Epping, NSW 2121, Australia*
[2]*News Limited, 2 Holt Street Surrey Hills, NSW 2010, Australia*

Accepted 1996 July 26. Received 1996 June 24

ABSTRACT
A search for Čerenkov emission in the radio-frequency range resulting from the particle cascade of an ultrahigh-energy neutrino on the near surface of the Moon is described. The expected pulse of 1-ns duration, dispersed by propagation through the Earth’s ionosphere, with an amplitude of approximately 400 Jy was not detected in approximately 10 h of observations.

PG* was at JPL, doing VLBI observations at Goldstone, and Chuck Naudet had discretionary research time…

* I first heard about the D&Z paper from Dan O’Connor!

The Goldstone Lunar ultra-high energy Neutrino Experiment (GLUE)

- Chuck Naudet, Kurt Liewer, and PG then of JPL. Access to the amazing 70m Deep-Space Network (NASA/JPL/Caltech) Goldstone radio telescope and its partners

- Gorham came to UCLA, invited Saltzberg to join (with grad student Dawn Williams)

Goldstone 70m tourism

Los Angeles Times

TRAVEL & EXPERIENCES

Calling All Space Nuts

By SUSAN E. JAMES

Jan. 3, 1999 12 AM PT

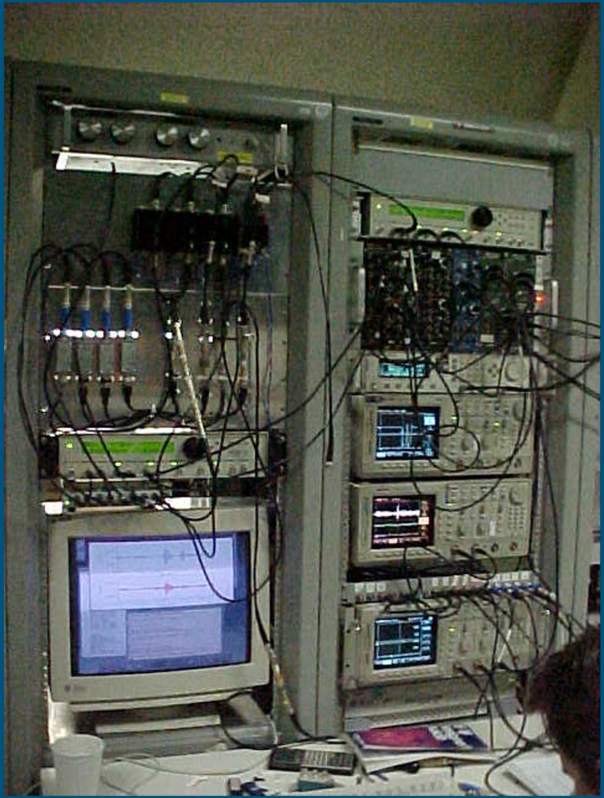
Share

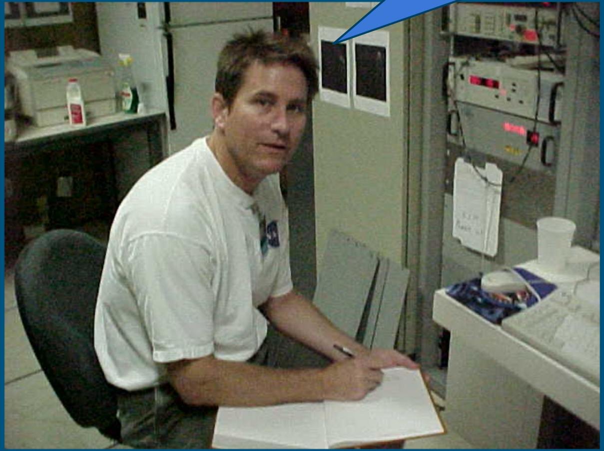
JAMES IS A LA CANADA-BASED FREELANCE WRITER

BARSTOW, Calif. — Long ago, in another lifetime far, far away, I used to drive out to Barstow once a week to read the strain gages on deep space antennas. This was in the early 1980s, when I worked at the Jet Propulsion Laboratory (JPL) in La Canada as part of the Deep Space Network (DSN). The strain gages monitored any unscheduled movement of the antennas, such as might be caused by an earthquake. The DSN was

"This antenna is so powerful," Barbara informed us, "that if you were to hide an apple in the hand of the Statue of Liberty, the antenna could find it in a microsecond." Twenty-one stories high, the great antenna sits in the desert

The GLUE control room (1998-2003)





Peter: "David, you are an accelerator-based guy. Can we show we are not wasting our time?

More GLUE Folks

Kurt Liewer

Chuck Naudet

Dawn Williams

+an article in "American Scholar"

Moonshine and Glue

A Thirteen-Unit Guide to the Extreme Edge of Astrophysics

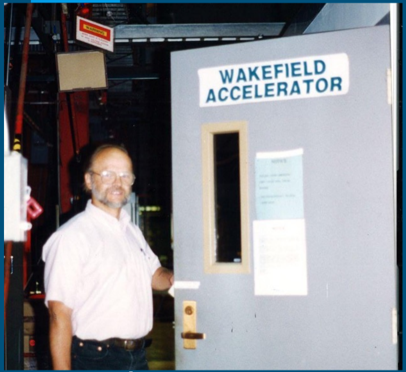
OLIVER MORTON

1. NANOSECONDS

PRESS RELEASE

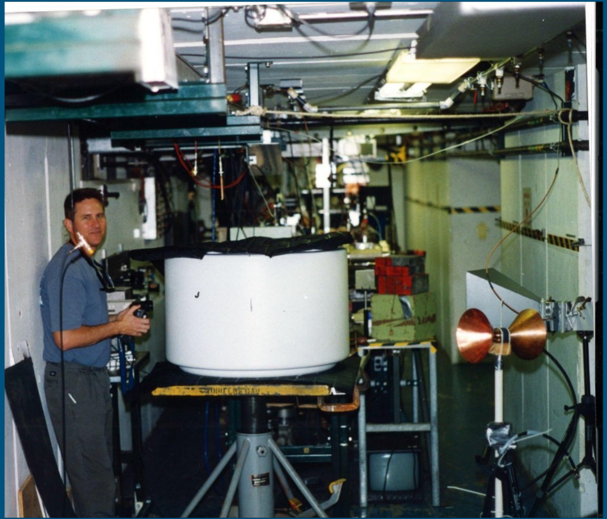
David Schramm Award to Writer Oliver Morton for Article on High-energy Neutrinos

The Argonne Wakefield Accelerator (AWA)



Dick Konecny

Paul Schoessow



Ordering the target:

-- "*What kind of gas station do you operate?*"

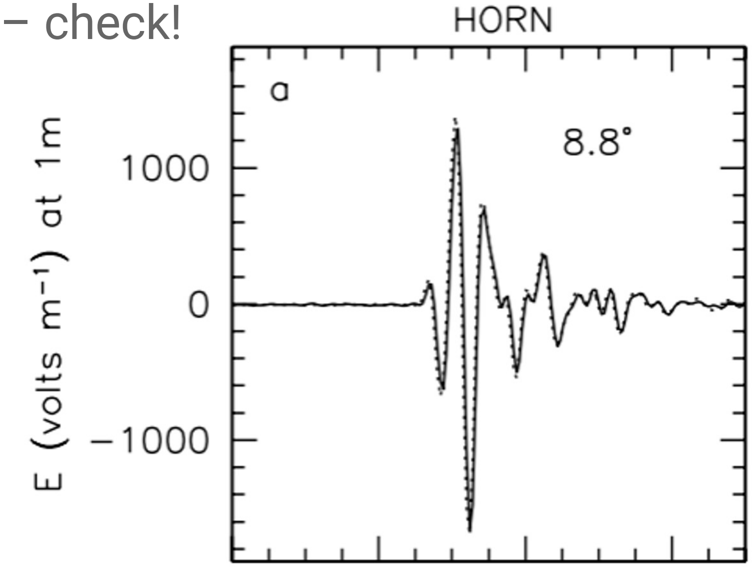
6 $\times$ 100lb. bags of silica sand

+ Wei Gai, John Power, Manuel Conde

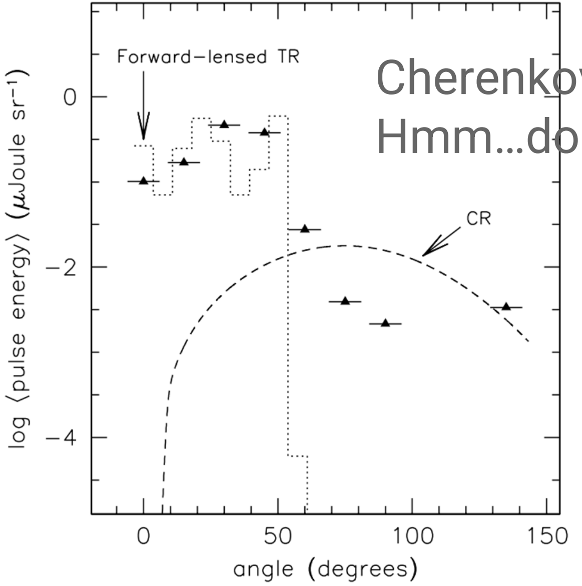
AWA results

Phys.Rev.E 62 (2000) 8590-8605

Coherent transition radiation – check!



Cherenkov?
Hmm...doubtful



Sort of suggestive but not yet the "slam dunk" to the community.
Hard to separate Cherenkov Radiation from Transition Radiation
(Generally a pretty awful first attempt, but we learned a lot.)

PG: "Always publish” (eg. Askaryan)
AWA paper → invitation to SLAC by Al Odian

15 GeV electron beam, converted to ~ 2 GeV photon beam at SLAC's Final Focus Testbeam

Photons → no charged particles to begin with, showers were not “biased”

Now 4 tons of sand

"The Kitty Litter Experiment"   2000

Lots of volunteer help

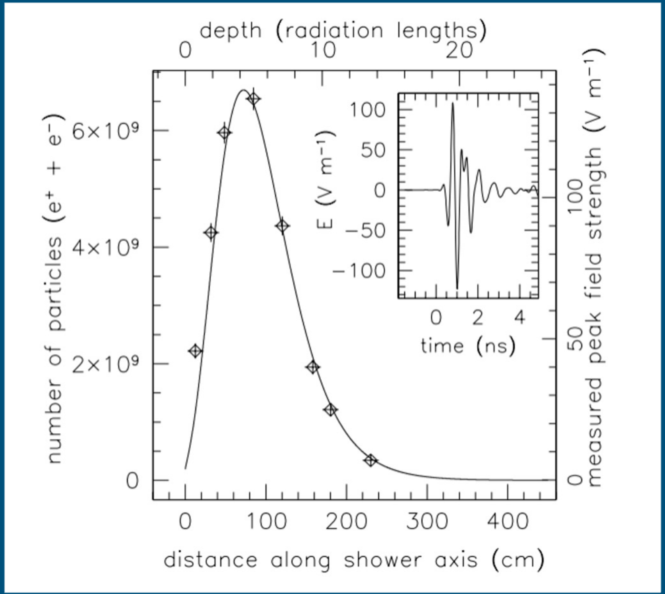
The amazing Dieter Walz!

"There's a cat in your target!"

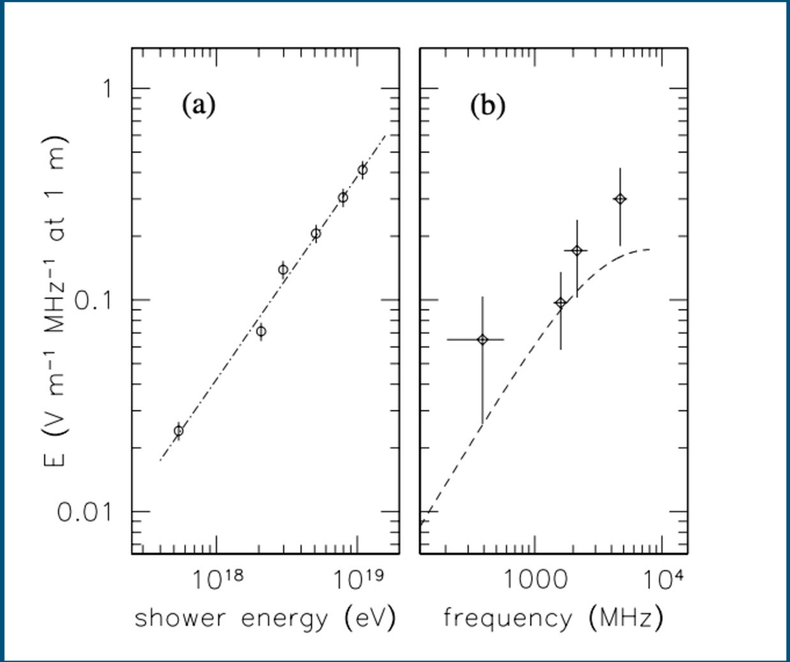
Very clear results

Phys.Rev.Lett. 86 (2001) 2802-2805

Curve: EGS sim
Data: Scaled RF power



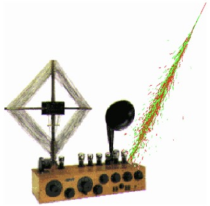
Curves: coherent Cherenkov prediction
Data: calibrated RF signal



The field of Radio Detection of High Energy Particles had a renaissance

RADHEP-2000

**First International Workshop on
Radio Detection of High-Energy Particles**



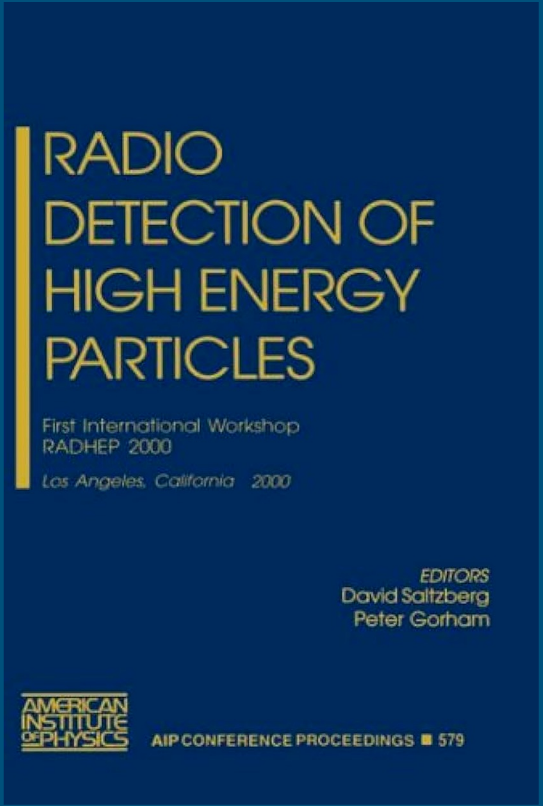
** Trasnsparencies **

** Write-ups **

** Worshop Photos **

** List of Participants**

**UCLA Faculty Center
University of California, Los Angeles
November 16-18, 2000**



From RADHEP2K, future possibilities?

UHE/EHE Neutrino Detector possibilities

medium	*area*	*depth*	*solid angle*	*E_thr*	*type*	*description*	*reference*
Antarctic ice	(see results at this conference)					present RICE array	this conf.
Antarctic ice	1e4 km^2	2 km ice	~2pi	1e18	VA	super-RICE array	RICE colla
Antarctic ice	1.2e6 km^2	~150m	~0.1	1e19	EA	balloon at 30km altitude	...
Greenland ice	1.8e6 km^2	~90m	~0.05	1e20	EA	geostationary orbiter	...
Earth atmosphere	1.6e7 km^2	10mwe	~1	~1e20	EA	Space station array	...
Dry lake array	160km^2	10mwe	~0.1	3e16	SA/EA	lakebed surface array	...
Auger array	5e3 km^2	10mwe	~3	1e19	SA	deep EAS, in constr.	Zas et al. 98
Goldstone	2e6 km^2	10mwe	0.05	1e20	EA	existing experiment	this conf.
super-Goldstone	7.5e6 km^2	20mwe	0.05	2e19?	EA	bigger beam, more BW	...
Compact salt array	10 km^2	100m salt	2pi	1e16	VA	instrument existing mines	M. Chiba, RICE grp.
Giant Salt array	3e4 km^2	300m salt	2pi	1e18	VA	0.5% US evaporite area	M. Chiba, RICE grp.
Lunar orbiter	1.2e7 km^2	20mwe	0.1	1e18	EA	h ~ 2 lunar radii	...

balloon at 30km altitude

Balloon-borne neutrino detector?

Seemed a bit wild at the time, but would NASA try it?

Antarctic Impulsive Transient Antenna (ANITA)

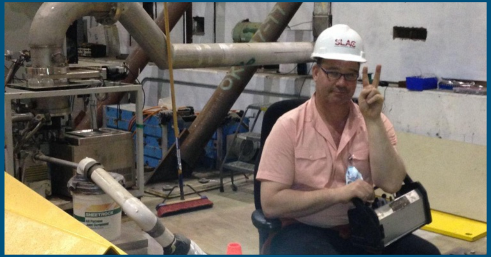
- Balloon payload over ice sheets – best "figure of merit" for cosmogenic neutrinos, so we decided to explore in more detail
  - Went to Berkeley: George Smoot (who had himself done radio experiments in Antarctica): **"This is a nice idea, but NASA will NEVER fund it!"**
- Fortunately he was wrong! In 2003, NASA did fund it for an Antarctic flight
- "ANITA-lite" flew in late 2003, with two antennas to test EMI environment
- ANITA flew in late 2006, after completing its pre-launch "hang test" at SLAC End Station A, where the payload was calibrated with 8 tons of ice blocks – verifying the Askaryan effect for ice

Several Askaryan Experiments at SLAC, including ANITA calibration

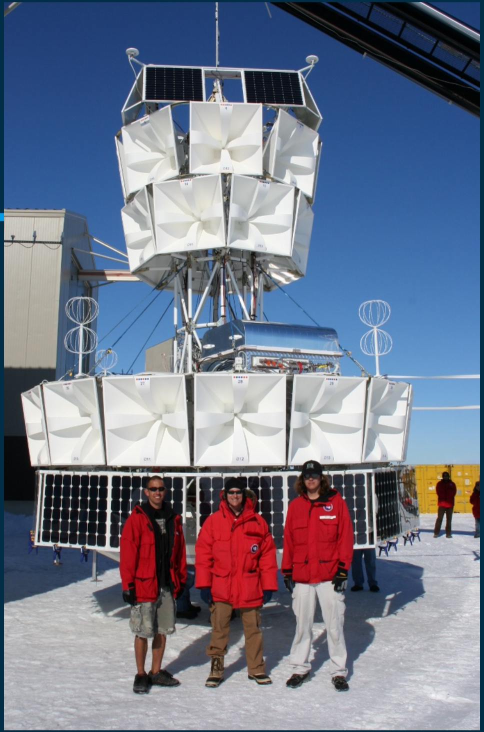
"Yes, you can iron ice."
---Abby Vieregg & Amy Connolly

4 tons of "salt licks"
+ a year's supply of Morton's salt from Menlo Park Safeway

Thank you, Carsten Hast!

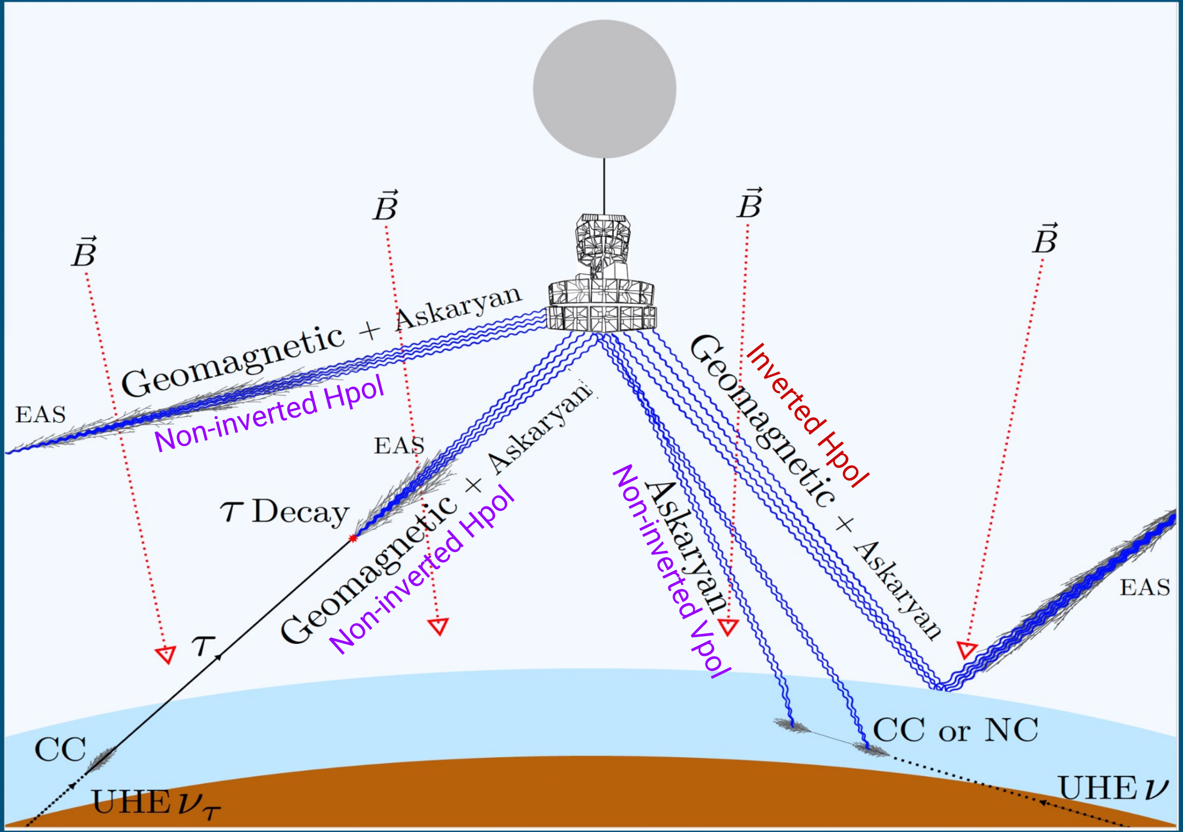


(No power cords were daisy chained, we promise)



ANITA-1 at left, ANITA-3&4 at right.
Four flights complete by 2017, nearly 100 days at float, around 70 ultra-high energy cosmic rays, no clear-cut neutrinos, but some other strange stuff

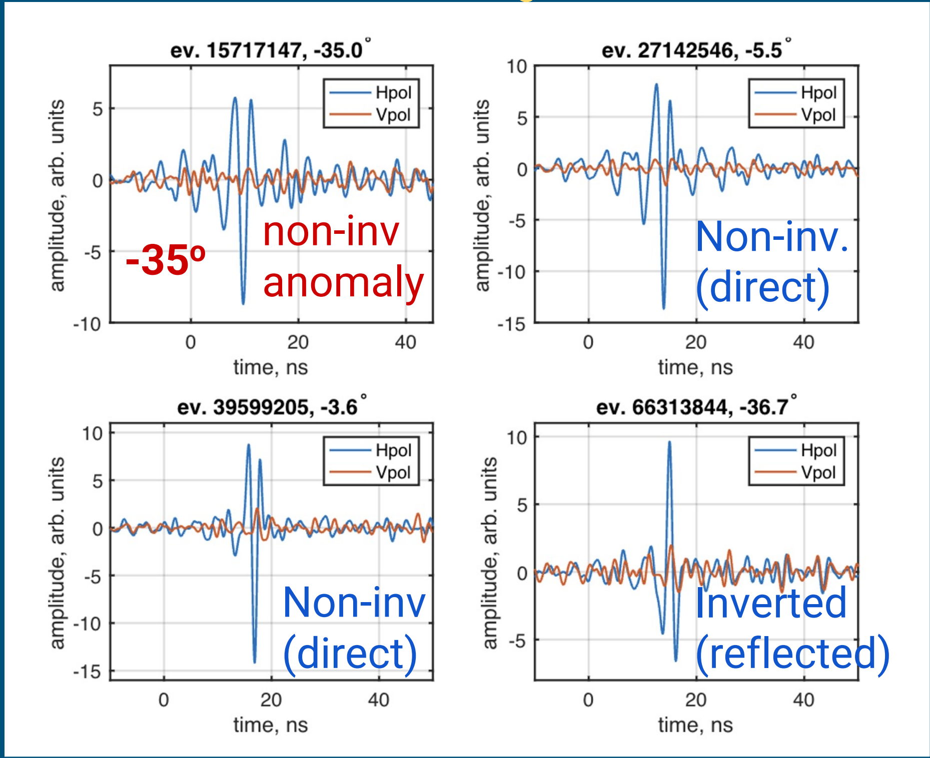
Seeing neutrinos/CRs with ANITA



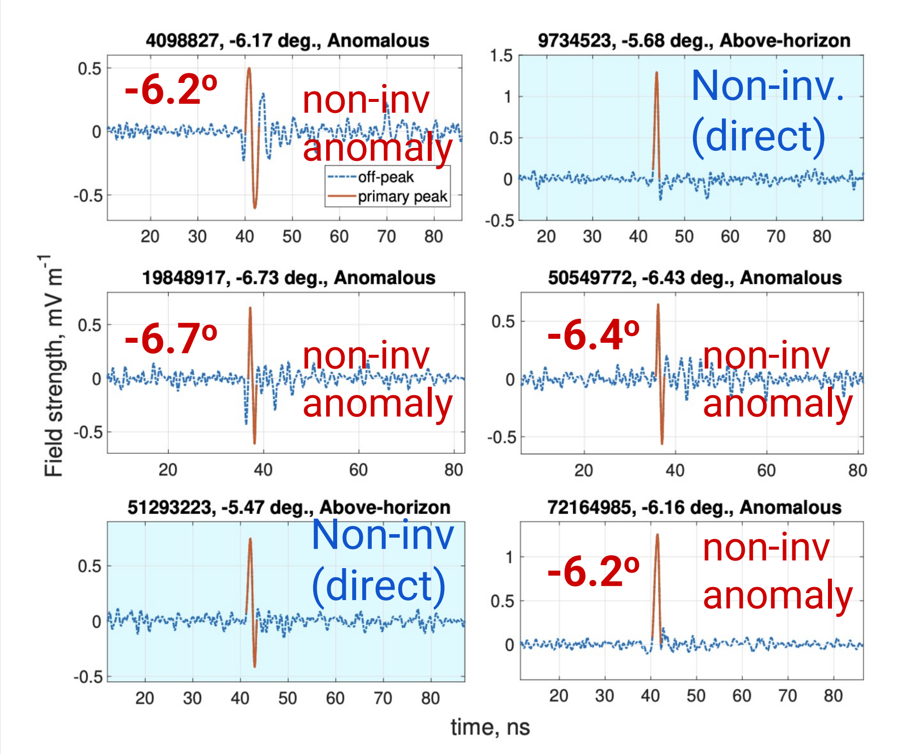
- Cosmic rays are 10:1 reflected vs. direct
  - Reflections always flip pulse polarity
- Neutrinos seen by subsurface cascades
- OR above-surface tau decay (eg. as a cosmic-ray event)
- CRs: horizontally polarized (vertical B)
- Neutrinos: Vpol due to transmission Fresnel

5 unexpected CR events from ANITA 3(left) & 4(right)

A3: Phase convention negative non-inv



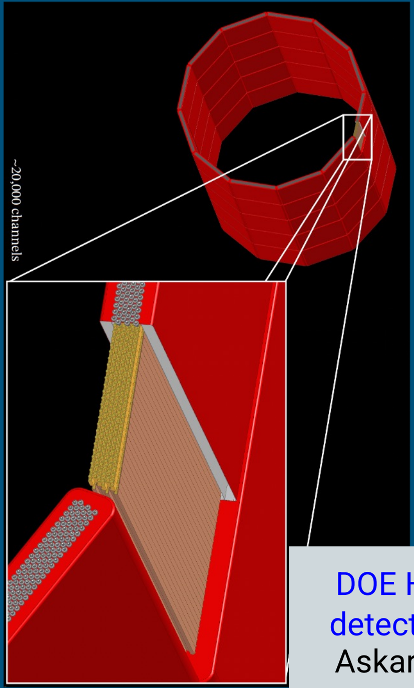
A4: phase convention positive non-inv



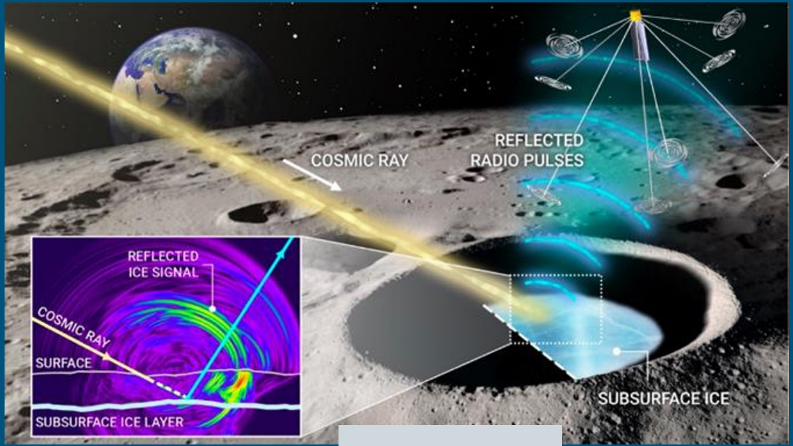
Events not yet explained, but are problematic if interpreted as tau neutrino decay showers – implied flux is in tension with Auger and IceCube

Current and future applications

NASA Pioneers: Payload for Ultra-high Energy Observations (PUEO)



DOE HEP detectors: Askaryan Calorimeter Experiment (ACE)



NASA Planetary: Cosmic Ray Lunar Sounder (CoRaLS)

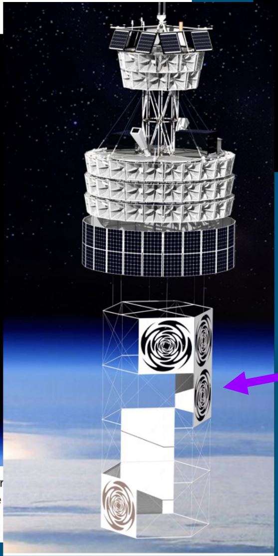
Payload for Ultra-high energy Observations (PUEO)

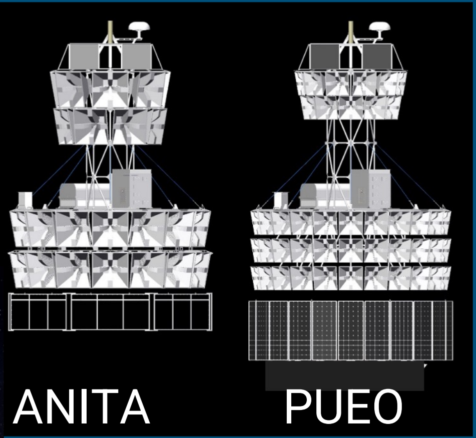

NASA selects astrophysics mission to detect ultrahigh-energy neutrinos

January 13, 2021

SHARE

NASA is funding concept development for a new astrophysics mission to detect ultr
neutrinos. Washington University is part of a University of Chicago-led team for the
Energy Observations (PUEO) mission.

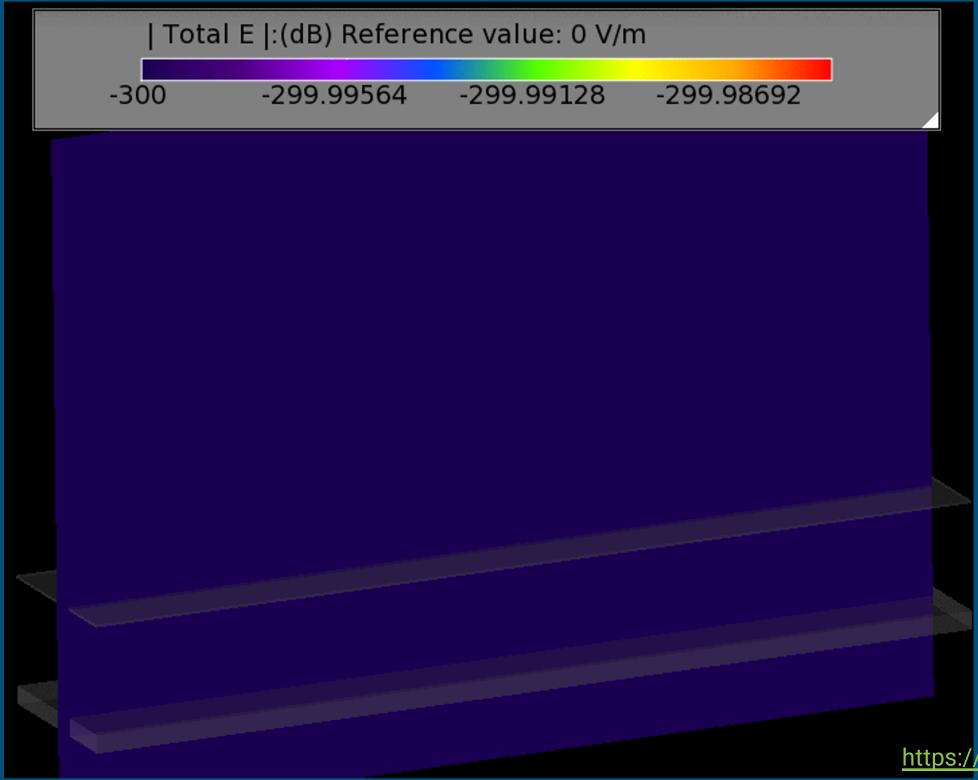




Low-frequency
Antenna array
Deploys after
launch

- Successor to ANITA, led by former Saltzberg student, Abby Vieregg (U. Chicago, P5 member)
- Payload funded by NASA *Astrophysics Pioneers* program, a new payload class
- Should exceed ANITA sensitivity by > 1 order of magnitude
- Due to launch this December!

Cosmic Ray Lunar Sounder (CoRaLS)




Geophysical Research Letters
Research Letter | Open Access

Cosmic Rays and the Askaryan Effect Reveal Subsurface Structure and Buried Ice on the Moon

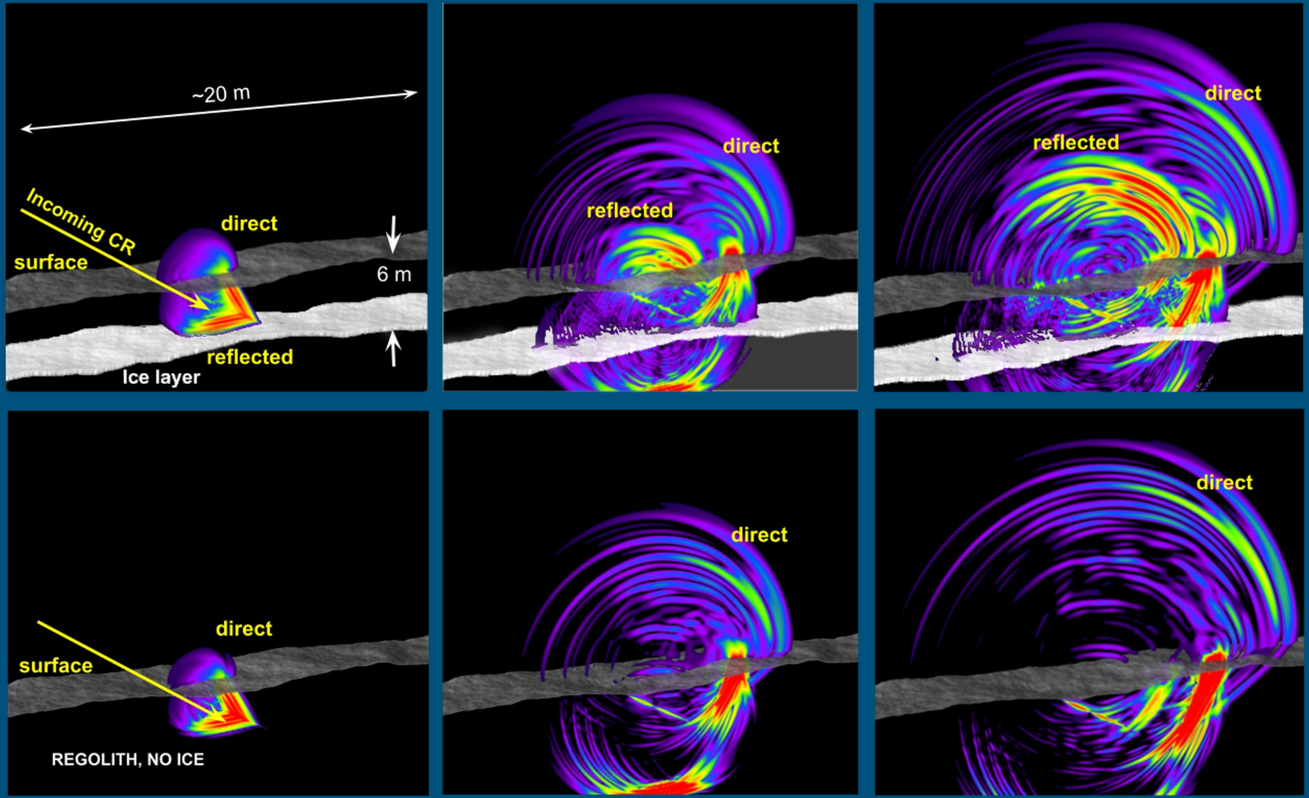
E. S. Costello, R. R. Ghent, A. Romero-Wolf, P. W. Gorham, P. G. Lucey, C. J. Tai Udovicic, P. Linton, A. Ludwig, K. McBride, C. Miki, E. Oberla, J. Rolla, A. Jung

First published: 26 March 2025 | https://doi.org/10.1029/2024GL113304

- Cosmic rays impact the lunar regolith continuously, creating subsurface RF pulses
- These will reflect off buried ice layers if they are within ~20m of the surface in permanently shadowed polar regions, can be detected by **lunar orbiter**
- CoRaLS was awarded $3M for TRL advancement in NASA’s Planetary science division
- Also a possible surface instrument for Artemis Lunar lander!

https://www.phys.hawaii.edu/~gorham/Post/iceSignal_ideal.gif

CoRaLS: realistic subsurface bistatic sims



- Huge ice deposits seen on Mercury in permanent shadows
- Why not the Moon? Buried?!
- LCross impactor excavated ~5m, saw water vapor
- Need subsurface radar to probe 3-30 meters for potential large ice deposits

Much debt to Gary Varner

- Gary's help and companionship through these years was essential, and a highly treasured memory.

- Without Gary’s marvelous instrumentation, none of this would have been possible

Conclusion:
Accelerator confirmation of Askaryan effect has had wide-ranging consequences

- Coherent Radio Cherenkov is essential to EeV neutrino astronomy
  - Many projects completed, current, and planned, with world-beating constraints in place
- ANITA helped fuel a renaissance in radio detection of UHE cosmic rays
- Coherent radio Cherenkov from cosmic rays showering in airless solar system bodies may provide probes that no other method can rival!